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Topical Report

ANALYSIS OF CURRENT TRENDS IN ENHANCED OIL RECOVERY PROJECTS

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ABSTRACT

The main trend NIPER found in EOR (enhanced oil recovery) project starts was a decrease in the number started each year from 1981 through 1985. This decrease was mainly caused by the decline in oil prices that began in 1982. The only exceptions to the downward trend are polymer and immiscible gas projects which, after dropping in 1982, came back stronger than before. The only trend in selecting reservoirs for EOR is toward selecting those having characteristics well within screening criteria, which makes them lower risk projects. Planned projects for 1986 appear to have reversed the decline in project starts; however, the recent dramatic drop in oil prices is causing companies to reevaluate these projects. Oil produced by thermal oil recovery already has dropped about 5 percent from February to September 1986, and many gas projects are being canceled. This analysis was performed under DOE contract, and results are based on DOE's EOR Project Database which is periodically updated by NIPER. This database contained information on 1,104 EOR projects that had been started before January 1986.

INTRODUCTION

One of NIPER's tasks (BE2A, Task 3) for DOE is collecting data on new and recently reported EOR (enhanced oil recovery) projects for inclusion in DOE's EOR Project Database. As part of this task, NIPER analyzes the technological/methodological trends in these projects. Analyzing these trends requires answering questions such as: are projects going deeper? are they

[1] Project Leader.

getting larger or smaller? are reservoir characteristics changing? and then determining why these things are or are not happening.

Over the main period of this report (Sept. 1, 1985 to Sept. 1, 1986), interest in initiating EOR projects went through a brief period of increasing popularity. This interest declined rapidly, beginning in February, to the present situation where almost no projects are being started, and some existing projects are even being canceled. In October of 1985, the press was reporting on the importance of EOR projects and how they were adding to the reserves of this Nation. Some states passed, and other states are considering, tax incentives for EOR projects.

The most important factor effecting EOR projects is the price of crude oil. Table 1 shows how the price has changed since 1979. The rapid drop in the price of oil early in 1986 drastically changed the outlook for EOR. By August 1986, many planned EOR projects had been placed on hold; only those projects having funds previously committed are continuing, and even these are being scaled down where practical. EOR operators are hoping the price of oil will increase before they have to completely shut down their projects.

TABLE 1. - Average U.S. crude oil prices

Year	1979	1980	1981	1982	1983	1984	1985	1986[1]
Wellhead price, $/bbl	12.64	21.59	31.77	28.52	26.19	25.88	24.09	14.50
Refiners' cost, $/bbl	17.72	28.07	35.24	31.87	28.99	28.63	26.76	16.10

[1] Midyear estimate.

Trends in the characteristics of EOR projects started since 1980 are analyzed in this report which is based mainly on the data in the DOE EOR Project Database[1] updated by NIPER and outlined in table 2. The data on EOR projects started before Jan. 1, 1986, collected by NIPER during fiscal year 1986, have been included in this and other tables in this report.

THERMAL PROJECTS

The thermal EOR processes are the most important of all EOR processes in terms of oil production, contributing about 80 percent of the total U.S. EOR production. The Oil & Gas Journal[2] reported 365,000 BOPD (barrels of oil per day) for 151 active projects in 1984 and estimates 480,000 BOPD for 206 active thermal projects in 1986. Total EOR production was 461,000 BOPD in 1984 and 605,000 BOPD in 1986. NIPER's version of DOE's database contains information on more than 450 thermal EOR projects (table 2) that had been started by Jan. 1, 1986. More than 95 percent of the thermal oil production comes from steam projects, and more than 90 percent of the projects and production are in California.

TABLE 2. - EOR projects in the DOE Database (1-1-86)

Process code	Process	Number of projects
1	Miscible fluid displacement	177
2	Conventional steam drive	320
3	Unconventional steam drive	39
4	Microemulsion flooding	87
5	In situ combustion	86
6	Polymer waterflooding	255
7	Cyclic steam injection	17
8	Alkaline flooding	49
9	Immiscible gas displacement	64
10	Heavy oil recovery	5
X	Other	5
	Total	1,104

According to the Division of Oil and Gas, State of California, daily oil production from thermal EOR projects has declined about 5 percent since the price of oil dropped early this year. Thermal projects have not been affected quite as much as other EOR processes by the drop in the oil price because most of the production cost is related to the price of the fuel used to generate the heat.

NIPER has collected information on 17 new thermal projects planned for the first 9 months of 1986. Since the number of EOR projects is being cut back, it is doubtful that all of these planned projects will be started this year.

Conventional Steam

Steam drive is the most important of the thermal processes, contributing more than two-thirds of the oil produced by those processes.

A summary of the available information on steam drive projects started in 1980 through 1985 is given in table 3. All of these projects are in sandstone formations, and well over 90 percent of them are in California. Comparison of tables 1 and 3 shows that as oil price increases the number of steam drive projects increases, with both peaking in 1981. Another small increase in project starts was seen in 1984 when the price of oil seemed to be stable.

The areas are reported to provide same concept of size. Reported sizes range from 1½ to 5,070 acres. One problem is the way a project's size is perceived by the operating company. One operation might report a 5-acre project knowing it may be expanded to 1,000 acres, whereas another might consider that project as a 1000-acre project with only 5 acres currently active. Over the period 1980 through 1982, the depth and API gravity of these projects increased as operators tried light oil steamflooding and more risky projects when the oil price was up.

TABLE 3. - Steam drive (2) projects

Start Year	(1) Majors #/Total	(2) Area, acres	(3) Avg depth	(4) Range depth	(5) Avg API	(6) Range API	(7) Avg porosity	(8) Range porosity
1980	12/16	373	1101	120-2500	13.4	8-21	32.0	20-42
1981	24/32	85	1411	350-3000	14.5	2-30	29.3	18-37
1982	17/20	59	1716	700-3500	14.0	8-30	30.9	7.5-37
1983	10/14	145	1095	300-2550	12.4	11-16	34.0	31-38
1984	14/20	112	1304	350-1900	13.7	11-18	33.3	29-37
1985	15/18	44	1578	350-4400	13.3	8-22	31.5	16-40

(1) Number of projects started by major oil companies/total EOR projects started.

(2) Average reported area in acres.

(3) Average depth to top of producing formation in feet.

(4) Shallowest project - deepest project.

(5) Average API gravity.

(6) Range of API gravities.

(7) Average reported porosity.

(8) Range of porosities.

NIPER has collected information on 16 steam projects with planned start dates before Oct. 1, 1986. Several of these are expansions (one vertical) of old projects. Information on the number that have been canceled or postponed is not available.

Cyclic Steam

Only one new project for 1986 was identified as a cyclic (huff 'n' puff) steam project. Many of the steam drive projects used the cyclic steam process to get started but are not counted as projects under this process. Information is available on only seven project starts in the 80's. This is not enough information to establish statistical trends for this process.

TABLE 4. - In situ combustion (5) projects

Start Year	Majors #/Total (1)	Area, acres (2)	Avg depth (3)	Range depth (4)	Avg API (5)	Range API (6)	#SS/ #Carb (7)	Avg porosity (8)	Range porosity (9)
1980	6/10	121	877	150-2350	23.3	14.7-32	10/0	23.2	18-36.9
1981	3/3	31	1283	950-1500	19.9	15-29	3/0	28.4	19.7-33.1
1982	1/1	112	1100	1100	21	21	---	38	38
1983	---	--	----	--------	----	-----	---	----	-----
1984	---	--	----	--------	----	-----	---	----	-----
1985	2/2	17	2650	500-4800	19.5	18-21	---	33	28-38

(1) Number of projects started by major oil companies/total EOR projects started.

(2) Average reported area in acres.

(3) Average depth to top of producing formation in feet.

(4) Shallowest project - deepest project.

(5) Average API gravity.

(6) Range of API gravities.

(7) Number of projects reported in sandstone/number in limestone.

(8) Average reported porosity.

(9) Range of porosities.

In Situ Combustion

Only one new in situ combustion project was reported as started in 1986, and only two in 1985. As can be seen in table 4, there are not enough projects to show trends. Although it is not obvious from the table, 1980 was the peak year for this process which currently seems to be out of favor.

Other Thermal Projects

Unconventional steam and heavy oil recovery projects are included in this category. Unconventional steam was originally defined as steam at depths greater than 2,500 feet or API gravities lower than 10. The values in table 3 show that this classification is not always applied. This category probably should be eliminated. The only valid trend is in the number of project starts which corresponds with oil price. There are not enough projects in these

TABLE 5. - Unconventional steam (3) projects

Start Year (1)	Majors #/Total (2)	Area, acres (3)	Avg depth (4)	Range depth (5)	Avg API (6)	Range API (7)	#SS/ #Carb (8)	Avg porosity (9)	Range porosity
1980	2/5	106	2773	2100-3200	7.8	2-14	5/0	29.5	29-30.1
1981	5/7	97.2	3472	2701-4500	20.0	10-47	7/0	30.3	18-34.4
1982	3/3	100.7	2675	2600-2850	14.6	13-17	3/0	28.5	27-30
1983	1/1	80	3400	3400	11	11	1/0	30	30
1984	1/1	--	3800	3800	22	22	---	31	31
1985	0/1	--	9000	9000	13	13	---	35	35

(1) Number of projects started by major oil companies/total EOR projects started.

(2) Average reported area in acres.

(3) Average depth to top of producing formation in feet.

(4) Shallowest project - deepest project.

(5) Average API gravity.

(6) Range of API gravities.

(7) Number of projects reported in sandstone/number in limestone.

(8) Average reported porosity.

(9) Range of porosities.

categories to calculate any other trends. No new project starts were reported for 1986.

During this time period, only three EOR projects have been classified as heavy oil, another poorly defined term. Since most of these projects use heat from sources other than steam or combustion, they should be in a separate category called Other Thermal Projects.

CHEMICAL PROJECTS

Polymer projects continue to be the most popular (in terms of the number of new projects started) of all EOR processes, whereas microemulsion and alkaline projects are still out of favor. The lowering of oil prices can only increase this trend.

The Oil & Gas Journal[2] reported 13,400 BOPD for 138 chemical EOR projects in 1984 and 16,900 BOPD for 206 projects in 1986. These numbers also show that total oil production per project is small compared to that of thermal projects.

Microemulsion

This EOR process is complicated and expensive which is why the number of new projects started has declined so much since 1980. The number of projects (table 6) is too small to establish trends other than the decline of project starts. Although it is not shown in the table, 1980 was the peak year for project starts. During 1980 and 1981, more risky projects, (carbonates and deeper projects) were tried, which probably was the result of government incentives and rising oil prices. No new project starts were reported for 1986.

TABLE 6. - Microemulsion (4) projects

Start Year (1)	Majors #/Total (2)	Area, acres (3)	Avg depth (4)	Range depth (5)	Avg API (6)	Range API (7)	#SS/ #Carb (8)	Avg porosity (9)	Range porosity
1980	9/19	95	3624	510-7983	32.6	21-43	17/1	21.7	14.7-31.8
1981	3/3	38	3187	1600-5060	37	32-40	2/1	18.3	11-24
1982	2/3	----	1400	950-1800	37.7	29-45	---	20.7	20-21
1983	1/1	200	2317	-------	37	---	1/0	19	------
1984	1/1	10	3950	-------	27	---	1/0	28.8	------
1985	1/2	6	4250	3900-4600	29.5	20-39	1/0	14	------

(1) Number of projects started by major oil companies/total EOR projects started.
(2) Average reported area in acres.
(3) Average depth to top of producing formation in feet.
(4) Shallowest project - deepest project.
(5) Average API gravity.
(6) Range of API gravities.
(7) Number of projects reported in sandstone/number in limestone.
(8) Average reported porosity.
(9) Range of porosities.

Polymer

Polymer flooding is the least expensive of the chemical group and by far the most popular in terms of new project starts. Most of these projects are in the mid-continent area. The number of independent oil producers starting projects peaked in 1981 when oil prices were high and then fell off until 1985 when it increased dramatically. The cause of this rise is not fully known but probably is due to good economic results and better understanding from earlier projects. Although recovery for each polymer project is low, they are very popular because the cost per barrel of oil recovered is also low. The reason the peak for starts by major oil companies was delayed 2 years is not known. The windfall profit tax may have been involved.

Areas are given only as a rough guide for the reader; however, the overall increase in size with time is probably real. There appears to be a slight trend toward deeper projects; however, the deepest projects were started in 1982 and 1983.

Polymer flooding continues to be the most popular EOR process with 34 new projects started or planned for the first 9 months of 1986. The recent drop in oil prices may delay or possibly cancel some of these.

Alkaline

This process is complicated, moderately expensive, and rarely applicable which explains the small number of projects. The one new project started in 1986 involves the use of a small amount of co-surfactant. The only real trend is the decline in the number of projects. The large number of projects in 1980 was caused by the DOE Tertiary Oil Incentive program and rising oil prices. No new project starts were reported for 1983, 1984, or 1985.

TABLE 7. - Polymer (6) projects

Start Year (1)	Majors #/Total (2)	Area, acres (3)	Avg depth (4)	Range depth (5)	Avg API (6)	Range API (7)	#SS/ #Carb (8)	Avg porosity (9)	Range porosity
1980	6/19	927	4046	1500-7301	32.8	16-43	13/3	16.0	6.0-31.3
1981	17/32	1096	2904	125-8000	33.5	12-49	9/2	18.4	7.1-41.9
1982	16/25	1405	3851	550-12000	34.4	20-47	2/2	18.1	4.1-35
1983	38/46	1411	4409	1000-9800	35.3	23-48	8/4	16.3	9.6-30
1984	33/38	1240	4237	775-8700	32.4	17-42	18/7	18.9	7.7-42.3
1985	17/35	2785	4738	2500-9400	31.6	20-47	17/3	18.2	9.6-28

(1) Number of projects started by major oil companies/total EOR projects started.

(2) Average reported area in acres.

(3) Average depth to top of producing formation in feet.

(4) Shallowest project - deepest project.

(5) Average API gravity.

(6) Range of API gravities.

(7) Number of projects reported in sandstone/number in limestone.

(8) Average reported porosity.

(9) Range of porosities.

TABLE 8. - Alkaline (8) projects

Start Year (1)	Majors #/Total (2)	Area, acres (3)	Avg depth (4)	Range depth (5)	Avg API (6)	Range API (7)	#SS/ #Carb (8)	Avg porosity (9)	Range porosity
1980	3/13	1305	3400	405-10130	32.4	16-43	9/4	18.3	13.4-31
1981	3/8	198	5045	740-10250	30.0	18-42	7/1	24.5	13-32.1
1982	1/1	316	8011	-------	--	---	1/1	15.1	------

(1) Number of projects started by major oil companies/total EOR projects started.

(2) Average reported area in acres.

(3) Average depth to top of producing formation in feet.

(4) Shallowest project - deepest project.

(5) Average API gravity.

(6) Range of API gravities.

(7) Number of projects reported in sandstone/number in limestone.

(8) Average reported porosity.

(9) Range of porosities.

GAS PROJECTS

According to the Oil & Gas Journal[2] the total number of active gas projects in 1986 had increased about 24 percent, from 84 in 1984 to 104 in 1986. Oil production rates from these projects increased from 83,000 BOPD in 1984 to 108,000 BOPD early in 1986. DOE's EOR Project Database (table 2) contains information on 241 gas projects reported as started by the end of 1985. NIPER has collected information on 26 gas projects scheduled to start in the first 9 months of 1986. During July and August of this year, the news media have reported several projects being canceled or cut back.

Miscible

This is the second most popular EOR process (following polymer) in terms of new project starts since 1980. Gases used include hydrocarbons, carbon dioxide, flue gas, and nitrogen. Most recent starts use carbon dioxide. The major oil companies have committed large sums of money to developing carbon dioxide sources and are thereby committed to using this process.

The main trends seen in table 9 are the decrease in project starts since 1980-81 and the increase in major oil company participation since 1982. Most of these projects are in the Permian Basin of West Texas and New Mexico. Project areas range from 25 to 16,000 acres and are shown to provide an estimate of project size. Project depth appears to be getting shallower, which may be a real trend due to economics. NIPER has collected information on six new projects with start dates in the first 9 months of 1986. Oil production[2] from miscible projects increased from 75,000 BOPD in 1984 to 88,000 in 1986. These production numbers are based on the inclusion of all flue gas production as miscible and all nitrogen as immiscible.

TABLE 9. - Miscible (1) project

Start Year	Majors #/Total (1)	Area, acres (2)	Avg depth (3)	Range depth (4)	Avg API (5)	Range API (6)	#SS/ #Carb (7)	Avg porosity (8)	Range porosity (9)
1980	13/27	1610	5495	500-10400	36.1	18-45	14/12	17.4	9-31
1981	15/35	2531	7288	1200-16150	37.2	14-51	19/12	17.8	6-37
1982	4/10	649	7350	2300-10400	31.8	14-40	3/2	17.7	9-27
1983	11/13	4123	6780	4300-11270	36.5	27-43	4/3	21.2	8-33
1984	8/9	3452	6813	5050-13275	33.4	28-45	2/6	15.5	6-30
1985	12/14	3989	6132	1270-10750	32.8	20-41	5/7	15.1	8-30

(1) Number of projects started by major oil companies/total EOR projects started.

(2) Average reported area in acres.

(3) Average depth to top of producing formation in feet.

(4) Shallowest project - deepest project.

(5) Average API gravity.

(6) Range of API gravities.

(7) Number of projects reported in sandstone/number in limestone.

(8) Average reported porosity.

(9) Range of porosities.

Immiscible

Although some immiscible projects use nitrogen or flue gas, most use carbon dioxide at pressures below minimum miscibility. These projects include cyclic (huff 'n' puff), gas drive, and gas cap injection in dipping reservoirs. During recent years, oil production from this process has increased dramatically. According to the Oil & Gas Journal[2], carbon dioxide immiscible production increased from 700 BOPD in 1984 to 1,350 BOPD in 1986. Total immiscible production is estimated to be 8,000 BOPD in 1984 and 20,000 BOPD in 1986. These production numbers are based on including all nitrogen production as immiscible and all flue gas as miscible.

Information collected for DOE on immiscible projects started from 1980 through 1988 is summarized in table 10. As with polymer projects, the peak in starts occurred in 1983, 2 years after oil prices peaked. These projects

require more planning and longer lead times, which may have caused some of this lag.

Except for one of these projects, all were major oil company starts. The one, City of Long Beach, probably should be called a major since it represents a group of majors. Areas vary widely and are based on too few data and influenced by operator perception, leaving out three large projects (one in 1981, 1982, and 1985) would leave data indicating that project size is becoming smaller. This is probably a real trend caused by many new Louisiana offshore projects which usually have an area of less than 100 acres. Most immiscible projects are in Louisiana and Texas.

TABLE 10. - Immiscible (9) projects

(1) Start Year	(2) Majors #/Total	(3) Area, acres	(4) Avg depth	(5) Range depth	(6) Avg API	(7) Range API	(8) #SS/ #Carb	(9) Avg porosity	Range porosity
1980	4/4	588	8233	2900-11000	31	14-46	2/0	15.8	11.7-24
1981	5/6	1351	5500	1440-12000	43	38-47	1/2	14.8	3.8-33
1982	5/5	2943	5947	3785-9000	41	23-60	1/1	21.4	5.5-30
1983	16/16	380	5017	2600-10000	26	14-39	4/2	25.6	13-31.8
1984	12/12	231	7725	1300-18500	35	14-60	5/1	21.6	8-31
1985	11/11	2443	8384	1400-13125	34	28-42	5/1	19.0	4.5-30

(1) Number of projects started by major oil companies/total EOR projects started.

(2) Average reported area in acres.

(3) Average depth to top of producing formation in feet.

(4) Shallowest project - deepest project.

(5) Average API gravity.

(6) Range of API gravities.

(7) Number of projects reported in sandstone/number in limestone.

(8) Average reported porosity.

(9) Range of porosities.

NIPER collected information on 20 new projects with planned starts in the first 9 months of 1986. By summer, the news media were reporting that this year's drop in oil prices was causing many of these projects to be canceled, cut back, or postponed.

OTHER PROJECTS

This category includes such processes as electro-osmosis and oilfield mining. These are very high-risk processes, and few will be started in this period of declining oil prices. No reports of new projects were found.

CONCLUSIONS

EOR is not dead. The decline in oil price has caused layoffs, bankruptcies, and the shutting in of oil wells. In spite of this, many new projects are being started, and old ones are being continued. This is shown in table 11 which summarizes EOR project starts by year. In 1980 and 1981, miscible projects were the most popular, and since then polymer projects have been most popular. This year steam and immiscible projects appear to be increasing dramatically in the number of projects started, whereas the number of miscible project starts is falling off. The numbers for 1986 include planned projects which may have been canceled or postponed. The economics of each project are being very carefully studied, and only those with acceptable economic risk will be started. This results in almost no change in the characteristics of the projects in a process. In other words, the trend in reservoir characteristics is toward those of earlier successful projects.

TABLE 11. - Summary of EOR project starts each year by process

EOR Process	1980	1981	1982	1983	1984	1985	1986[1]
Steam	10	26	12	6	4	2	16
In Situ	10	3	1	0	0	2	1
Unconventional steam	5	7	3	1	1	1	0
Microemulsion	19	3	3	1	1	2	0
Polymer	19	32	25	46	38	35	34
Alkaline	13	8	1	0	0	0	1
Miscible	27	35	10	13	9	14	6
Immiscible	4	6	5	16	12	11	20
Total	107	120	60	83	65	67	78

[1] First 9 months.

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